Geothermics 72 (2018) 348–357

Contents lists available at ScienceDirect

Geothermics

journal homepage: www.elsevier.com/locate/geothermics

Drilling data from an enhanced geothermal project and its pre-processing for ROP forecasting improvement

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A R T I C L E I N F O

Keywords:
ROP prediction
EGS
Multiple regression
Neural network
FFT filtering

A B S T R A C T

Drilling parameters are analyzed here to improve forecasting of the rate of penetration (ROP) in enhanced geothermal systems (EGSs). Data recorded during drilling a 4.2-km-deep well at a pilot EGS project in South Korea were analyzed. The greatly fluctuating ROP values were smoothed using a fast Fourier transform filter. Two drilling optimization methods (multiple regression and artificial neural networks) then evaluated the effect of smoothing: it improved ROP prediction in both cases, with over 90% correlation at relatively low degrees of filtering. A methodology to optimize the degree of smoothness for a given drilling data set is suggested.

1. Introduction

The construction of any oil, gas, or geothermal well is expensive, and a substantial part of the cost is related to the drilling (Akin and Karpuz, 2008). According to the Independent Petroleum Association of America (IPAA), in 2009 the drilling cost per meter was $2203.74 for oil wells (Fitzgerald, 2012). However, geothermal projects tend to be more expensive than oil and gas drilling by 23% to 40% for a given depth (Lukawski et al., 2014). Furthermore, drilling costs for enhanced geothermal systems (EGSs) can be even higher, accounting for 42% to 95% of the total power plant cost (Augustine et al., 2006). Although improvements of drill bits and drilling technology in general have reduced costs, challenges remain, especially given that potential onshore and offshore drilling projects require ever greater depths. Therefore, cost reduction is important, and savings are possible when the drilling process is correctly modeled and the influencing factors are fully understood (Ismael and Hamad-Allah, 2008).

Drilling parameters are either controllable or uncontrollable. Controllable factors include weight on the bit or drilling force, bit rotational speed, bit type and size, hydraulics, and drilling fluid properties and type. In contrast, uncontrollable factors are weather, location, water availability, rig conditions, round trip time, formation properties, depth, bottom hole temperature, hole problems, and crew efficiency (Ismael and Hamad-Allah, 2008).

Drilling performance is generally improved by assessing drilling data and testing experimental design (Kaiser, 2009). The first approach analyzes and correlates data from different wells to establish suggestions. The second varies drilling parameters and measures their impact on cost or rate of penetration (ROP). The ROP expresses drilled distance per unit of time, and it has been used since the early development of the oil and gas industry as a parameter for drilling optimization (Amar and AlArfaj, 2012).

Data pre-processing can be required for three important reasons: incomplete data, noise, and inconsistency in the data. In particular, drilling data commonly include noise, and therefore data pre-processing is important for obtaining meaningful results (Pyle, 1999). The drilling data considered in this study contain noise, namely undesired ROP fluctuations, than can influence predictions and error calculations. This noise can be inherent in the mechanical components of the drilling equipment or it can be induced by field operation practices. Data preparation can be as time consuming as the processing, and consequently special attention should be given to the selection of one or multiple preparation methods to be applied (Zhang et al., 2003). In this regard, smoothing, the generation of a function that better captures intrinsic trends in the data, has proven effective, especially when employing computer algorithms to manage large amounts of data (Kotsiantis and Kanellopoulos, 2006). Among different smoothing techniques, the fast Fourier transform (FFT) has been applied successfully in a number of fields owing to its efficiency and versatility (Marmol and Jachimski, 2004; Ling et al., 2007; Sherlock et al., 1994; Heydt et al., 1999).

The present study aims to explore the relations among drilling parameters, particularly at greater depths of around 4 km, as well as to improve the accuracy of ROP forecasting. Drilling data from a pilot geothermal power project in South Korea were analyzed to plot the evolution of different drilling parameters recorded during the drilling of a well that reached a final depth of 4.2 km. We also employ a FFT filter

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https://doi.org/10.1016/j.geothermics.2017.12.007
Received 19 June 2017; Accepted 12 December 2017

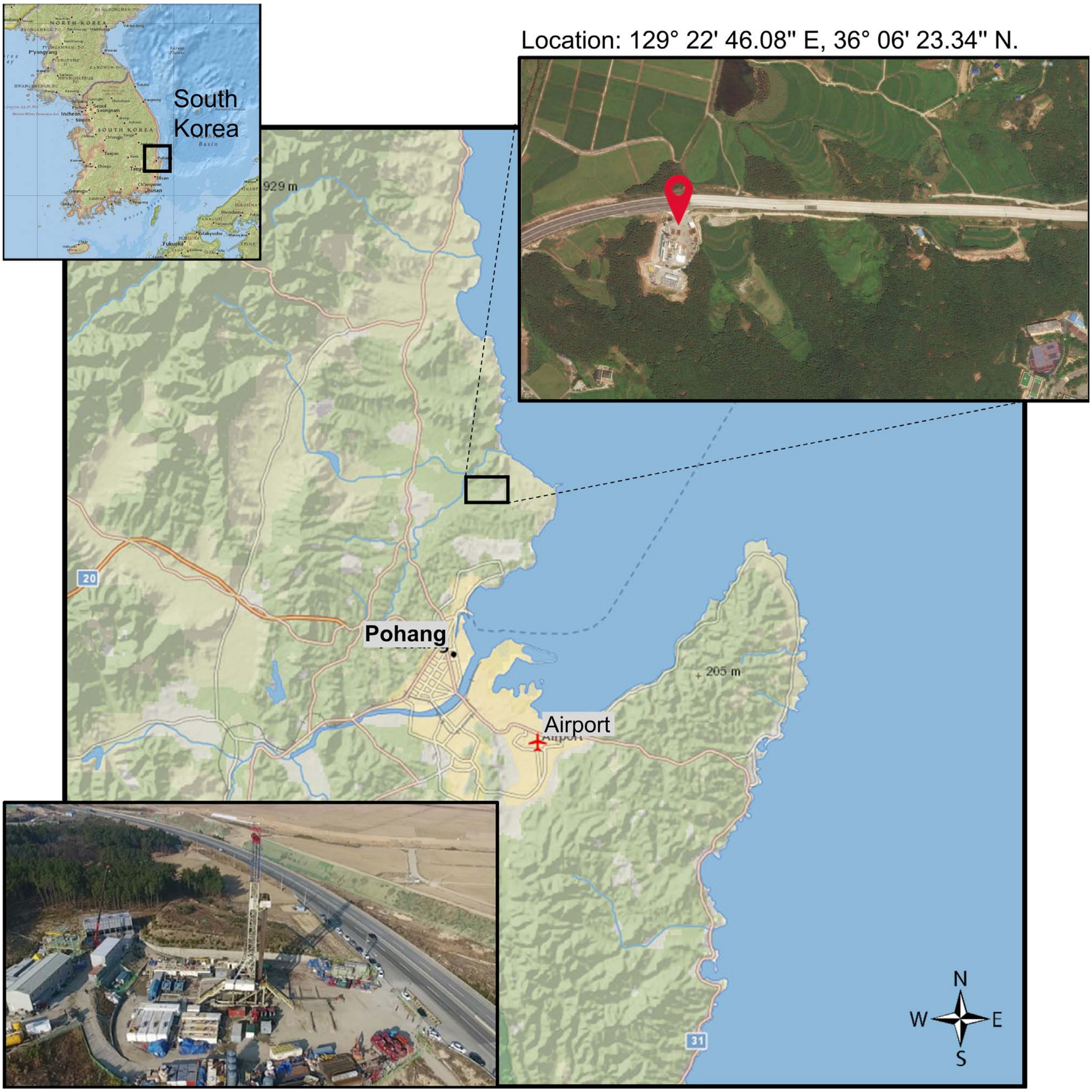

Fig. 1. Location of the enhanced geothermal power project in Pohang, South Korea.

to smooth the measured ROP data and analyze the effect of the degree of smoothing on the prediction performance of two drilling optimization methods: the first is traditional multiple regression (Bourgoyne and Young, 1974), and the second is the artificial neural network (ANN) approach that has reported practical applicability to well planning, procedural optimization, well stability, pattern recognition, decision making, and problem solving (Bello et al., 2015).

2. Project location and recorded drilling parameters

2.1. Pohang geothermal project

The drilling data come from a geothermal wellbore near the major port city of Pohang, Gyeongsang Province, South Korea (Fig. 1). Launched in 2010, this is the first EGS of the Korean government. It aims to demonstrate enhanced geothermal technology, and is expected to produce 1 MW of electricity. Wells PX-1 and PX-2 have been completed, and the next step comprises improving the reservoir permeability.

Only drilling data from PX-1 are considered here; casing sections and major stratigraphic divisions for this well are thus shown in Fig. 2. The first 200 m is mostly mudstone, followed by other sedimentary rocks and tuff to a depth of 2.3 km. The main bedrock, where the stimulation is due to take place, is predominantly granodiorite and granite. The well has a total measured depth of 4127 m (Diaz et al., 2016).

2.2. Recorded drilling parameters

Various drilling parameters were recorded nearly every meter; however, Table 1 lists typical values for only 14 of these. The drilling record included depth, pore pressure gradient of the formation, equivalent circulation mud density at the bottom hole, weight on the bit, bit diameter, rotary speed, tooth wear, mud density, flow rate,